AP® Chemistry

INCORPORATING GREEN CHEMISTRY

Student Workbook

AP® with WE Service

Table of Contents

Getting to Know the Topic

Pollution: Globally

Pollution occurs when harmful materials are introduced into the environment. The top five pollutants are ground-level ozone, particle pollution (or particulate matter), carbon monoxide, sulfur dioxide, and nitrogen dioxide. There are also other dangerous contaminants such as soot, cigarette smoke, volatile organic compounds (VOCs), formaldehyde, asbestos, and methane. These pollutants seep into our daily lives, impacting our planet and the humans and animals that live on it.

Poor air quality is one of the biggest global killers, affecting more than 100 million people around the world. It's been connected to higher rates of diseases such as cancer, heart disease, and asthma. Pollution also contributes to climate change and is one factor in the frequency of heat waves and the occurrence of other extreme weather conditions. It contaminates our water supplies, depletes nutrients in the soil for agriculture, and harms forests and crops, among other effects.

Fast Facts

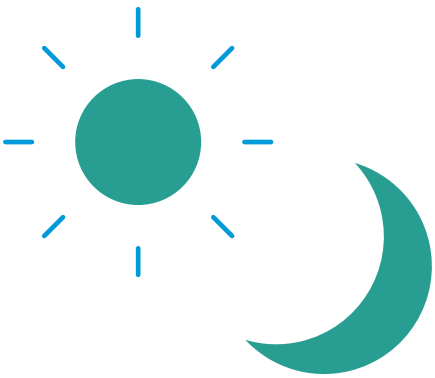
- Every year, about 8 million tons of plastic waste escapes into the oceans from coastal nations. That's the equivalent of setting five garbage bags full of trash on every foot of coastline around the world.
- 91% of the world's population lives in places where air quality does not meet World Health Organization guideline limits.
- Pollution kills more than 1 million seabirds and 100 million mammals every year.

Taking Action Globally

Pollution is an issue that impacts everyone around the world, and there are a number of ways students can support reducing pollution on a global level. Some ideas include:

- Research global organizations that are taking action against pollution and find one to support by volunteering or fundraising.
- Spread the word about pollution and climate change by setting up assemblies or speaking events.
- Attend an event with expert speakers to learn more about the issue.

Another option is to support and fundraise for the WE Villages program. Students can support this program by visiting **WE.org/we-schools/program/campaigns** to get ideas and resources for taking action on global water issues.



Humans have pumped enough carbon dioxide into the atmosphere over the past 150 years to raise its levels higher than they have been for hundreds of thousands of years.

Getting to Know the Topic

Pollution: Locally

In the U.S., pollution is a major issue. Despite making up only 5 percent of the world's population, Americans use up 25 percent of the world's resources, contributing to poor air quality. The U.S. burns up nearly 25 percent of the world's coal, 26 percent of its oil and 27 percent of its natural gas. Burning these fuels releases contaminants into the atmosphere, affecting health, water supply, agriculture, and more. Approximately 88 percent of U.S. national parks have high levels of air pollution that are directly impacting the environment, such as suppressing tree growth and altering soil and water chemistry.

Fast Facts

- Plastic pollution is an environmental issue that has increased exponentially, from 2.3 million tons in 1950 to 448 million tons in 2015. Plastic production is expected to double by 2050.
- The Mississippi River carries an estimated 1.5 million metric tons of nitrogen pollution into the Gulf of Mexico each year, creating a "dead zone" about the size of New Jersey in the Gulf each summer.
- Approximately 40% of the lakes in America are too polluted for fishing, aquatic life, or swimming.

Taking Action Locally

Within the local community, there are many ways for students to take action, such as:

- Working with a local organization that is taking action against pollution and climate change through volunteering, fundraising, or raising awareness.
- Create a proposal or petition to change a local law or decision around pollution.
- Take part in the WE Go Green campaign and encourage behavioral changes that will positively impact the environment.

With both their global and local actions, encourage students to be creative with the ideas they develop through their action plans.

An estimated 82 million people nationwide live in counties with air pollution above U.S. standards.

NAME: _____

TEAM MEMBERS: _____

It's Easy Being GREEN

As you sort the cards, write the description in the box next to each principle.

GREEN CHEMISTRY PRINCIPLE	DESCRIPTION	EXAMPLE/APPLICATION
Prevent Waste		
Atom Economy		
Less Hazardous Synthesis		
Design Benign Chemicals		
Benign Solvents & Auxiliaries		
Use Renewable Feedstock		
Reduce Derivative		
Catalysis		
Design for Degradation		
Real-time Analysis for Pollution Prevention		
Accident Prevention		
Design for Energy Efficiency		

NAME: _____

TEAM MEMBERS: _____

Green Chemistry Awards: A Step Toward Solutions

Each year the EPA (Environmental Protection Agency) recognizes the environmental and economic benefits of developing and using novel Green Chemistry. These prestigious annual awards recognize chemical technologies that incorporate the principles of Green Chemistry into chemical design, manufacture, and use. Recent winners can be found at **https://www.epa.gov/greenchemistry/green-chemistry-challenge-winners.**

Research the recent award winners. Discuss their name, their contribution, and what principle of Green Chemistry their effort utilizes. Put this research into a chart so that information from other groups can be added.

AWARD WINNER NAME(S)	DESCRIPTION OF PROJECT	GREEN CHEMISTRY PRINCIPLE ADDRESSED

NAME: _____

TEAM MEMBERS: _____

Redesign Challenge

Not all reactions that could be safely performed in a chemistry classroom are environmentally friendly. You are to redesign a common laboratory procedure to make it "greener." Use the 12 principles of Green Chemistry to assist in your redesign. Use the information in the MSDS provided, as well as your knowledge of efficient laboratory procedures.

Purpose: To quantitatively analyze a precipitation reaction to determine the percent of carbonate in a compound.

Materials available for use: Balance, beaker, graduated cylinder, deionized water, 50mL beaker, 250mL beaker, funnel, filter paper, stirring rod, sodium carbonate (Na_2CO_3), copper (II) carbonate ($CuCO_3$), barium nitrate $Ba(NO_3)_2$, iron (III), chloride ($FeCl_3$), zinc acetate ($Zn(C_2H_3O_2)_2$).

MSDS for sodium carbonate: **https://www.flinnsci.com/sds_716-sodium-carbonate/sds_716/**

MSDS for copper (II) carbonate: **https://www.flinnsci.com/sds_280-copperii-carbonate/sds_280/**

MSDS for zinc acetate: **https://www.flinnsci.com/sds_860-zinc-acetate/sds_860/**

MSDS for barium nitrate: **https://www.flinnsci.com/sds_96-barium-nitrate/sds_96/**

MSDS for iron (III) chloride: **https://www.flinnsci.com/sds_338-ironiii-chloride/sds_338/**

PROCEDURE	REVISION	REASON/PRINCIPLE
1. Weigh out 5.0g of silver nitrate into a 250.0mL beaker. Record the mass of the beaker empty. Record the mass of the beaker and silver nitrate.		
2. Add 100.0mL of deionized water to the beaker. Record the mass.		
3. Weigh out 10.0g of iron (III) chloride in a 250mL beaker. Record the mass of the empty beaker. Record the mass of the beaker and iron (III) chloride.		
4. Add 100.0mL of deionized water to the beaker. Record the mass.		
5. Add all of the silver nitrate solution to the iron (III) chloride solution.		
6. Write the names of the members of your group on a piece of filter paper. Fold the filter paper to fit in a funnel. Take the mass of the filter paper.		

PROCEDURE	REVISION	REASON/PRINCIPLE
7. Filter the precipitate product into a clean Erlenmeyer flask. Rinse both the beaker and precipitate several times with large amounts of water.		
8. Allow the precipitate to dry overnight. If a drying oven is available, dry the precipitate at low heat until dry.		
9. Take the mass of the dry filter paper and precipitate. Determine the amount of product produced.		
10. Discard of all materials as appropriate.		

Analysis:

1. Based on your results, calculate the percent of composition of carbonate in the reactant. Show all work including units and significant digits.

2. Identify the limiting reactant in the reaction. Provide evidence of your answer.

3. Determine the percent yield of your reaction.

NAME: _____

TEAM MEMBERS: _____

Problem Tree

In your Problem Tree graphic organizer, start by writing the problem in the trunk of the tree, and then look at the causes and effects of an issue. Keep digging to go deeper on the issue to find its supporting and root causes.

Leaves/branches: Effects

These are the results created by the problem. At first, this part of the issue appears easy to tackle, but when leaves and branches are trimmed, they grow back quickly. Consider the multi-layered effects, or "effects of effects," that can arise when a problem goes unaddressed. Always ask: "Then what happens?"

Ex. Contaminated waterways

Trunk: Problem

This is the key issue that is being studied. Because it is not as apparent as the leaves, the core problem itself sometimes takes a little longer to identify.

Ex. Harmful chemicals in fertilizers

Roots: Causes

These are the situations or factors that have led to the problem. When exploring the root causes of a problem, ask yourself "Why does this problem exist?" Dig deeper to consider the "causes of causes"—the multiple layers of factors that contribute to a problem.

Ex. Growing need for increased agricultural production

NAME: _____

TEAM MEMBERS: _____

Sticky Situations

Milk can be transformed into curds and whey by adding a mild acid such as acetic acid. After curds form and are separated from the whey, the acid is neutralized with the sodium bicarbonate.

The clumps of curds are comprised of casein, a protein found in milk. Casein proteins make up 3% of whole milk. Glues made from casein include products such as Elmer's and other woodworking glues. Casein can also be molded or poured into forms to making a variety of plastic items such as combs, beads, buttons, and umbrella handles.

In this lab you will make some "milk glue" and then compare it to more traditional glues to test its effectiveness.

Materials: Skim milk, vinegar (acetic acid), baking soda (sodium bicarbonate), Erlenmeyer flask, thermometer, beaker, coffee filter, hot plate, stirring rod, refrigerator, plastic acetate, wooden craft sticks, paper or cardstock, white glue, rubber cement

Procedure:

1. Pour 100 mL of milk into an Erlenmeyer flask, measure and add 15 mL of acetic acid.
2. Place the mixture on a hot plate, set the heat to 4, and heat. Stir gently with a glass stirring rod. Observe the mixture carefully, and stop when you see solid curds floating in the flask. Do not overheat mixture; the protein will denature (unravel), and your glue won't be sticky.
3. Filter the mixture, using a coffee filter, into a beaker. The curds should remain in the coffee filter, while the filtrate (liquid) passes into the beaker. Gently squeeze the coffee filter to press some of the excess filtrate through. Discard the filtrate in the sink; this contains the whey (sugars).
4. Scrape the curds from the coffee filter into a small plastic cup.
5. Add ½ teaspoon of baking soda ($NaHCO_3$) to the cup and stir with a wooden stick. Slowly add several drops of water, stirring continually until the consistency of white glue is obtained.
6. Paint a uniform and consistently sized circle of each adhesive between two pieces of each material (paper, wood, plastic acetate), gluing them together. Make two sets, one that will go into the refrigerator and one that will stay at room temperature. Record the temperature of the refrigerator and the room temperature in the data table.
7. Mark each sample with a relevant identification. Set the test samples aside to cure (convert from liquid to solid) at room temperature, and put the other test samples in the refrigerator.
8. Record the time at which all of the samples have begun to cure in the data table.
9. Allow to sit until next class period (at least 24 hours).
10. Have the group appoint a person as the official "force applier." Using the refrigerated samples first, have that person slowly separate each sample by gradually applying a pulling force, trying to separate the materials. By observing their "force applier," the group should rate the strength of the intermolecular forces, using a scale of 1–5, in which 1 is the weakest ability to hold the material together, and 5 is the strongest. Record all information in data table.

Analysis:

1. Write a CER (Claim, Evidence, and Reasoning) statement about the effectiveness of each adhesive. Be sure to include principles of intermolecular forces, adhesion, and cohesion in your reasoning.

2. Explain which of the 12 Principles of Green Chemistry were demonstrated in your manufacture of "greener" glue.

NAME: _____

TEAM MEMBERS: _____

Greener Clean

You are going to formulate a green cleaner using the simulation found at:
https://greenchemistry.yale.edu/education/undergraduate-graduate

Record your setting and results in the table below.

TRIAL #	PARAMETER 1	PARAMETER 2	PARAMETER 3	SUCCESS (YES/NO) EXPLANATION

Analyze

1. What parameters did you need to consider when making your cleaner, and why?

2. Did you succeed the first time? What prevented success?

3. What principles of Green Chemistry were illustrated in this formulation activity?

NAME: _____

TEAM MEMBERS: _____

Needs Assessment

The following series of questions helps you to analyze and identify ongoing areas of need within organizations addressing your issue.

1. Identify 3-5 organizations working on issues related to the issue your team is working on.

2. What does each organization do well in response to the issue and/or related issues?

3. What could each organization do better in its response?

4. What areas of need related to access to your issue have you learned about that each organization is NOT addressing?

5. Considering all 3-5 organizations, where are there ongoing needs that are not being adequately addressed?

6. Considering all 3-5 organizations, where are there ongoing needs that are being addressed successfully, and to which you can add further efforts to support the issue?

NAME: _____

TEAM MEMBERS: _____

Solution Tree

In your Solution Tree graphic organizer, start by rewriting the problem from your Problem Tree, and reframing it as a goal at the trunk of the tree. Then consider the different solutions (the roots) and possible outcomes of the solutions (the branches).

Leaves/branches: Outcomes

These are the results created by the solution. Results may appear as straightforward as having achieved goals, but when you consider the ripple effects and outcomes of sustainable results, the impact is far-reaching and long-lasting. Always ask: "Then what happens?"

Trunk: Problem

Trunk: Goal

Roots: Solutions

These are the actions needed to solve the problem and achieve the goal stated at the center of the Solution Tree. When exploring solutions, ask yourself "How will this solve the problem?" Dig deeper to think holistically, so that you are looking beyond the short-term and addressing not only the symptoms of the problem but the root causes as well.

NAME: _____

TEAM MEMBERS: _____

Reflect: Investigate and Learn

Now that you have investigated problems and potential solutions associated with implementation of Green Chemistry Principles, think back over what you have learned: How can what you are learning in your AP® Chemistry class support your solutions? Is the company/industry doing all they can to implement Green Chemistry?

Record your thoughts on the lines below. If you run out of room on this page, use additional paper to write a lengthier response. As you write, think about the following questions to help shape your reflection.

- What are the social impacts of Green Chemistry?
- As you investigated different companies addressing Green Chemistry principles, what did you feel these programs do well, and what did you feel they could do better?
- Does the company have a Sustainability Policy?
- Based on what you learned about your local and global issue and the actions others are already taking, what are five areas of need that you could address?
- What attracts you to these areas?
- What are some actions that you could take to address this issue?
- What excites you about these actions and the impact you can have?
- How can what you are learning in your AP® Chemistry class support solutions that improve Green Chemistry implementation?

NAME: _____

TEAM MEMBERS: _____

Summarizing Your Investigation

Summarize what you have learned from your investigation. Your work may be supported by multimedia or print materials that synthesize and analyze the topic and issue on local and global levels.

When summarizing your investigation, keep the following in mind:

- What are the key takeaways from your investigation of the Green Chemistry?
- How are the problems you investigated similar at local and global levels? How are they different?
- How are the solutions you investigated similar at local and global levels? How are they different?
- Why may your investigation be important to other AP® Chemistry students?

NAME: _____

TEAM MEMBERS: _____

Working Independently

Free Response Question 1

Mass of KI tablet	0.425
Mass of thoroughly dried filter paper	1.462 g
Mass of filter paper + precipitate after first drying	1.775 g
Mass of filter paper + precipitate after second drying	1.699 g
Mass of filter paper + precipitate after third drying	1.698 g

A student is given the task of determining the I-content of tablets that contain KI and an inert, water-soluble sugar as a filler. A tablet is dissolved in 50.0 mL of distilled water, and an excess of 0.20 M Pb(NO3)2(aq) is added to the solution. A yellow precipitate forms, which is then filtered, washed, and dried. The data from the experiment are shown in the table above.

a. For the chemical reaction that occurs when the precipitate forms, write a balanced, net-ionic equation for the reaction, and explain why the reaction is best represented by a net ionic equation.

b. Explain the purpose of drying and weighing the filter paper with the precipitate three times.

c. In the filtrate solution, is [K+] greater than, less than, or equal to [NO3-]? Justify your answer.

d. Calculate the number of moles of precipitate that is produced in the experiment.

e. Calculate the mass percent of I- in the tablet.

f. In another trial, the student dissolves a tablet in 55.0 mL of water instead of 50.0 mL of water. Predict whether the experimentally determined mass percent of I- will be greater than, less than, or equal to the amount calculated in part (e). Justify your answer.

g. A student in another lab also wants to determine the I- content of a KI tablet but does not have access to Pb(NO3)2. However, the student does have access to 0.20 M AgNO3, which reacts with I-(aq) to produce AgI(s). The value of Ksp for AgI is 8.5 x 10-17.

i. Will the substitution of AgNO3 for Pb(NO3)2 result in the precipitation of the I- ion from solution? Justify your answer.

ii. The student only has access to one KI tablet and a balance that can measure to the nearest 0.01 g. Will the student be able to determine the mass of AgI produced to three significant figures? Justify your answer._

Approaches to Taking Action Information Sheet

DIRECT SERVICE		
WHAT IS IT?	Personally engaging with and providing hands-on service to those in need (usually in conjunction with an organization).	
EXAMPLE GOAL	By the end of the semester, we will support a local food bank and shelter by packing and serving food to people in the community. We will also visit our neighboring elementary school and teach a lesson on food insecurity in our community.	
ACTIONS	• Reach out to local shelters and food banks to arrange a day for the class to visit and provide hands-on support • Once a date has been decided, make sure students all have permission to travel to the food bank (if during school hours)	• Connect with teachers/administration at local elementary school and arrange to visit a classroom to teach a lesson to young students on food insecurity • Create and print worksheets to use with younger students

INDIRECT SERVICE		
WHAT IS IT?	Channeling resources to the needs of a community—locally, nationally, or internationally.	
EXAMPLE GOAL	By the end of the year, we will create a storage and donation system for local families in need, where they can access furniture and other household items. We will develop a system for donations, pick-ups, and inventory.	
ACTIONS	• Conduct research into which items are most needed by community members (e.g., bed frames, dining tables, household goods, etc.) • Reach out to local businesses to try to get a storage space donated • Connect with school social workers/ administration to gain their support • Put up flyers around school and in the community, asking for donations (list specific items needed), including instructions on how/where to donate	• Develop an online database for tracking donations and pick-ups, and maintaining inventory • Share pick-up information with local shelters, churches, community centers, etc. • Share the donation system with school social workers, so that they can maintain the project in future years

ADVOCACY		
WHAT IS IT?	Educating others about an issue to increase visibility and following up with an action that focuses on enacting change. Actions around advocacy often look like raising awareness, but without a strong call to action within the initiative as a whole. Educating others is not considered service in and of itself.	
EXAMPLE GOAL	Through an informative art piece, we will educate our school community about the waste created by single-use plastic water bottles, and the impact they have on the environment. Then, we will sell reusable water bottles at school, and the proceeds from the sale will go toward clean water projects in developing countries.	
ACTIONS	• Research the impact of single-use plastic water bottles around the school and in the local community • Plan out and create a 3D sculpture that incorporates informative text on the issue of single-use plastics • Seek permission from school administration to display the piece in a common area of the school	• Design and order water bottles to sell at school • Research and select an international organization that focuses on clean water projects • Organize a selling schedule for the water bottles, donate profits

NAME: _____

TEAM MEMBERS: _____

Creating the Action Plan

This outline serves as a basic template for your action plan. Use additional space and resources to help you build out each part with the right amount of detail and flow to ensure you have the strongest action plan that you and your team can implement with ease. Remember, this is your road map for your service project!

TEAM GOAL:

MEASURES OF SUCCESS:

Required Network and Resources

In order to complete this goal, our team will need to develop the following network and access the following resources:

NETWORK:

RESOURCES:

ROLES AND RESPONSIBILITIES
Each team member will take on the following roles and associated responsibilities:

TIMELINE
Our team will use the following timeline to complete tasks and successfully carry out the action to meet our goal(s):

NAME: _____

TEAM MEMBERS: _____

Five Action Planning Pitfalls Tip Sheet

Once your team has completed the major components of your action plan (creating your teams and setting goals, timeline, and network), review the five action planning pitfalls provided below to ensure these have been avoided. Review your plans—individually first, then together as a team. After the review, rework your action plans, if necessary.

1. **Setting an unclear goal**
   The first and most important part of any action plan is defining the goal, or what you want to achieve. It should be clear and easy to understand, for example, "We want to collect 500 cans of food," or "We want 200 people to learn about WE Villages." If the goal is not clearly defined, proper planning will be difficult if not impossible. As a best practice, have a peer from another team review your goal to ensure it is as clear as you hope.

2. **Planning unrealistic actions**
   After the goal is set, begin planning the actions necessary to achieve it. It is important that the steps make sense and are achievable. Do not plan unrealistic actions, such as working at times that will interfere with schoolwork, overestimating how many people can help out, or planning to go to places that would be difficult for you to reach. Consider each team member's school and community schedule, such as work and extracurricular activities. Before planning an action, ask yourself, "Is this action realistic?"

3. **Rushing the process**
   Do not be too hasty in planning actions. While you may be excited to start, proper planning takes time. The better the planning and organization, the more success you will achieve. Even if it means slowing down to figure out details, do not rush and leave out important steps.

4. **Not asking for help**
   Do not be afraid to ask for help. When a network is created, bigger goals can be achieved faster. Reach out to friends, parents, and mentors. People generally enjoy helping, especially if it is for a worthy cause.

5. **Not learning from mistakes and giving up too quickly**
   We all make mistakes—it is normal and healthy. Mistakes allow us an opportunity to learn and grow. So, learn from the mistakes. Ask, "Why did this happen?" and "How can I avoid this problem next time?" Actively think about the mistakes and how it will be better the second time around. If something does not go as planned, do not stop!

NAME: _____

TEAM MEMBERS: _____

Reflect: Action Plan

Your team now has a plan for taking action globally and locally. Think back over what you have learned: What problems associated with access to clean water does your team's action plan address? How does your individual role in the plan support your team's action?

As you write, think about the following questions to help shape your reflection. Begin at the "Start Here" bubble and go clockwise to record your thoughts on the lines below. Use additional paper to write a lengthier response.

NAME: _____

TEAM MEMBERS: _____

Student Log Sheet

DATE / TIME SPENT	ACTIVITY, DESCRIPTION, AND REFLECTION	VERIFIED BY (NAME, ORGANIZATION)

Notes

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